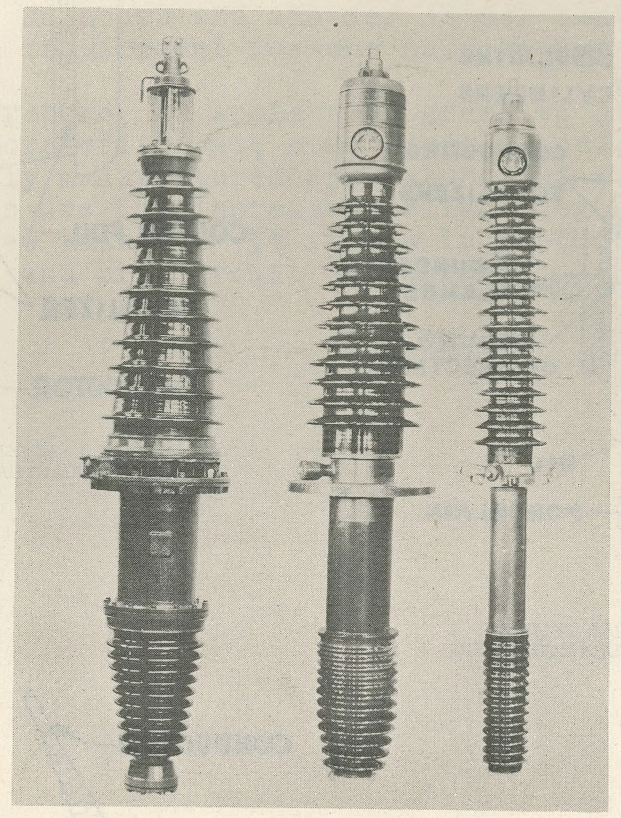

Figure 4. Comparative size 138 KV bushings--(left and center)--full turn equalizer resin-bonded cylinder designs--(right)--new conducting line equalizer design.

Bergain

Transactions Paper

(Reviewed and Accepted for Publication)

A NEW APPARATUS BUSHING WITH IMPROVED VOLTAGE DISTRIBUTION

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A paper recommended by the AIEE Committee on Transformers and approved by the AIEE Committee on Technical Operations for presentation at the AIEE Winter General Meeting, New York, N. Y., January 30-February 3, 1956. Manuscript submitted October 20, 1955; made available for printing December 13, 1955.

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A New Apparatus Bushing with Improved Voltage Distribution

L.W. Spooner - J.E. Bergain

Introduction:

A high voltage bushing can be described as a short, shielded, insulated conductor consisting principally of two ends. One end usually terminates in the insulating fluid within a high voltage transformer or oil circuit breaker while the other end most often terminates in air. To achieve successful and efficient operation, it is necessary to control the electric field through and about the bushing completely, and so pack a maximum amount of dielectric strength into the space between the conductor and the outside diameter or grounded portion of the bushing. A well designed bushing must embody an adequate radial puncture strength and an adequate axial creepage strength. The method of controlling the voltage distribution through or over the bushing is subject to many mechanical variations but the principle remains the same. The fundamental objective is to provide a smooth and uniform gradation in voltage both axially and radially between the central conductor and the external grounded supporting ring.

To accomplish this objective, the older bushing construction employed an assembly of concentric resin bonded paper cylinders and intervening oil ducts, each cylinder containing a full turn embedded conducting equalizer. This construction provided voltage control only at discrete intervals, Fig. 1.

Description and Advantages of the New Bushing Design

It is the purpose of this paper to describe the advantages of the new bushing design which utilizes a means to obtain a smooth or more uniform control of voltage distribution throughout the entire insulation rather than at only discrete intervals which obviously limits the number of equalizers that can be used in any design. The major inovation eliminates (1) oil ducts and (2) resin bonded paper, and provides (1) oil impregnated wrapped paper, with (2) voltage distributing means on every other turn of paper. This new and unique construction, Fig. 2, is basically as follows:

The voltage distributing means consists of a paper on which are printed narrow conducting lines. The conducting lines run across the paper web so that, when a bushing core is wound, the lines run in the axial direction and occur on the paper in close frequency around the circumference. The new bushing core is wound with two papers, one containing the conducting axial lines and the other is plain insulating paper. The plain and lined papers are tapered mechanically when wound, the plain paper extending axially further on each end than the lined paper to provide adequate axial creepage distance. The core winding is usually terminated with

a full turn conducting layer or ground sleeve with a metallic contact strip. The entire structure, after assembly into the terminal porcelains, is completely impregnated with 10-C oil.

The conducting lines are applied onto the paper by a printing process prior to the winding of the bushing core. Winding the core with plain and lined paper is a simple winding procedure, unencumbered by addition of adhesive as in the manufacture of resin bonded paper or by interruptions to introduce intermittently any conducting elements as used in previous methods of manufacture.

Because of the improved voltage distribution (controlled at every other turn), the diameter of the core and consequently the size of the major components are greatly reduced from prior bushing designs which contribute to lighter weight and easier handling.

Narrow conducting lines do not short circuit any insulation as does the complete turn equalizer which is overlapped to be certain that a complete turn is provided.

The bushing manufacture is a much more mechanized procedure and is to a large extent free from manual errors.

The absence of gas pockets in the oil impregnated core or anywhere in the bushing structure due to the vacuum treatment, greatly increases the voltage at which corona occurs. Because there are no voids, ionization of gases cannot occur. This increases the voltage level at which the bushing can be worked without danger of encountering the losses and insulation destroying effects of corona. Likewise it greatly increases the voltage at which radio noise starts in the bushing.

Consequently, a more reliable bushing is available, with a shorter manufacturing cycle.

Conducting Lines

The printing of the conducting lines on the insulating paper is performed using a new Gravure Apparatus and Process*. The feature of principal importance and novelty in this new method of gravure printing is that the printing is done from continuously open grooves in the design applicator roll. The conducting ink deposited from such grooves provide continuously conducting lines while a deposit from conventional cellular grooves result in a line of discontinuous dots. The bushing design would normally specify that the conducting lines run straight across the sheet. However, it is necessary to arrange them in a herringbone pattern in the applicator roll to print a continuous deposit from the open grooves.

* patent applied for.

The conducting ink found preferable is one loaded with finely divided graphite powder to provide the desired conductivity and containing an organic resin to bond the graphite firmly to the paper. The lacquer base organic resin found desirable has good, fast drying properties suitable for rapid printing as well as durable resistance to vapor phase drying and 10-C transil oil used subsequently in the bushing manufacture. This conducting ink provides a surface resistivity in the order of 1000 ohms per square. So, if the lines are about 25 mils wide, the resistance of each line is about 40,000 ohms per inch or 4 megohms per 100 inches.

A 25 mil wide line is about as narrow as is practical to provide, and a spacing of seven lines per inch gives an adequate insulating spacing between lines. The resistance then between adjacent lines 100 inches long is at least 5000 megohms. The conducting ink does not appreciably penetrate the paper sheet on which it is printed, therefore, does not impair its quality as an insulating sheet.

Selection of Paper

The requirements of the paper insulation used in the new bushing design differ from those of older concentric resin bonded paper cylinder-oil duct designs. Resin penetration for the manufacture of resin bonded paper is no longer required. Instead, a smooth calendered surface is required for the rapid printing of a conducting compound on its surface without penetration into the interior of the sheet. A Fourdrinier made paper is used to provide the best dimensional stability especially in the cross-machine direction. High density paper provides optimum dielectric strength and good oil penetrability. Fortunately all of these requirements are available in a dry calendered, dense Fourdrinier made Kraft paper.

Bushing Core Winding

With the new design bushing, a greatly simplified and more reliable core winding procedure is used. There is no need for intermittent stopping to spray complete turn equalizers as in an alternative method of producing bushing cores, Fig. 3. There is no need for winding, baking, transporting and assembling resin bonded paper cylinders. Rather, using master or jumbo rolls of line paper and plain paper, the new design merely requires winding a sheet of each continuously onto the conductor. The edges of each sheet are trimmed off accurately and mechanically, providing the required tapers at each end during the winding operation. When the simple and rapid core winding operation is completed, the core is ready for assembling as a part of the final bushing in which it is thoroughly dried and vacuum oil treated.

In this process the gases within the paper are drawn off. With the core still held in a positive pressure of not more than 400 microns, the bushing is filled with oil that has been thoroughly dried and freed of gas. The oil is introduced into the hot bushing and held under pressure until the paper is completely oil impregnated. Dry nitrogen at slight pressure is introduced into the space at the top of the bushing to exclude oxygen and to maintain positive pressure. The result is an oil impregnated insulated structure surrounded by oil and hermetically sealed within the bushing.

Since the voltage distributing means (the conducting lines) occur on alternate layers of paper, tapering is commenced immediately. The principle of voltage distribution involves essentially (1) constant voltage per turn, (2) constant capacitance per turn, and (3) constant area of capacitance electrodes per turn which decrease in length as the circumference increases. The ratio of tapers between the top and bottom ends depends on the immersion media of each terminal porcelain, and other design features including a correction between positive and negative impulse performance.

To the slight degree that constant area per turn is not provided geometrically with a straight line tapered build up, it is preferred to obtain the desired external voltage distribution with linear tapers and accept the mild relief in the form of lower stress in the central radial volume of the core thus providing a lower stress rate where heat dissipation is less.

Comparison of Diameters and Radial Stresses with Older Designs

Because the use of conducting lined paper introduces thousands of individual equalizers with an infinitesimal voltage drop between them, in the core structure of the new bushing, a far more uniform voltage gradient from conductor to ground is obtained as compared to the sharp peaks of dielectric stresses present in the older bushings. The older designs, Fig. 1 and 3, utilize complete turn equalizers spaced radially and terminated axially at relatively large intervals. The use of lined paper has resulted in far more efficient utilization of the core insulation and a relatively sizeable reduction in the bushing diameter and weight. Two older design bushings employing resin bonded paper cylinders are contrasted in diameter with the new bushing in Fig. 4.

The 60 Cycle Electrical Tests

This new design bushing is electrically equivalent or superior to the older design bushings in all ratings and complies with all requirements of AIEE, ASA and NEMA Standards. Each rating of the new design was subjected to ten sixty cycle one-minute rated withstand tests interspersed by ten sixty cycle flashovers and followed by thirty minutes at the one minute rated withstand voltage. No

rise in the initial low power factor or other indication of deterioration was noted on completion of these tests.

Exhaustive design and life tests which proved the superiority of this new bushing design were carried out. These tests included actual field tests for as long as 3 years. Severe mechanical shock tests were endured satisfactorily. One rating withstood the required 60 cycle one minute tests for 24 hours and another 43 per cent more than the one minute 60 cycle test requirement for one half hour without incident.

The new bushing, therefore, is another progressive step in the continuous search for more efficient, more closely controlled, and more accurately and rapidly manufactured apparatus. Of even more importance to customers are the increased reliability and longer life expectancy of this new bushing. It is now in production and is being used on transformers and oil circuit breakers.

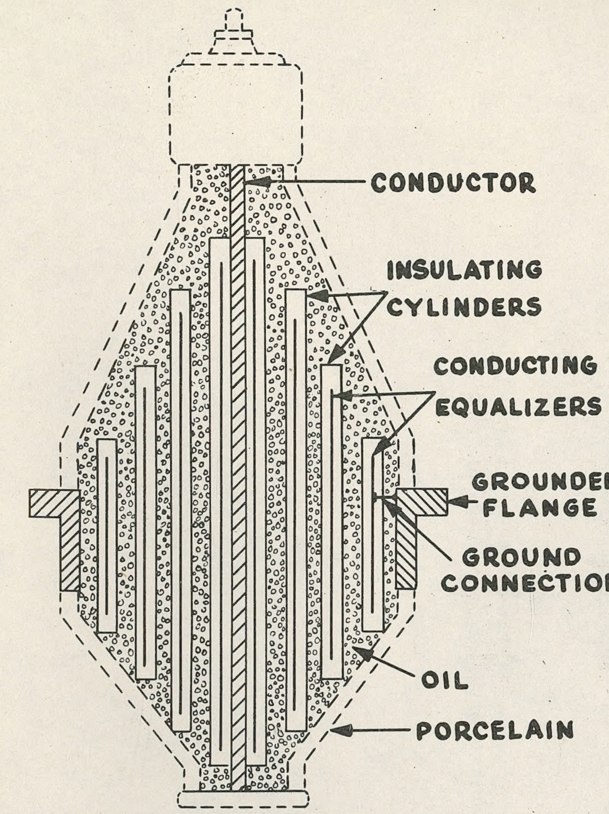


FIGURE 1. RESIN-BONDED PAPER CYLINDER BUSHING DESIGN WITH FULL TURN EQUALIZERS.

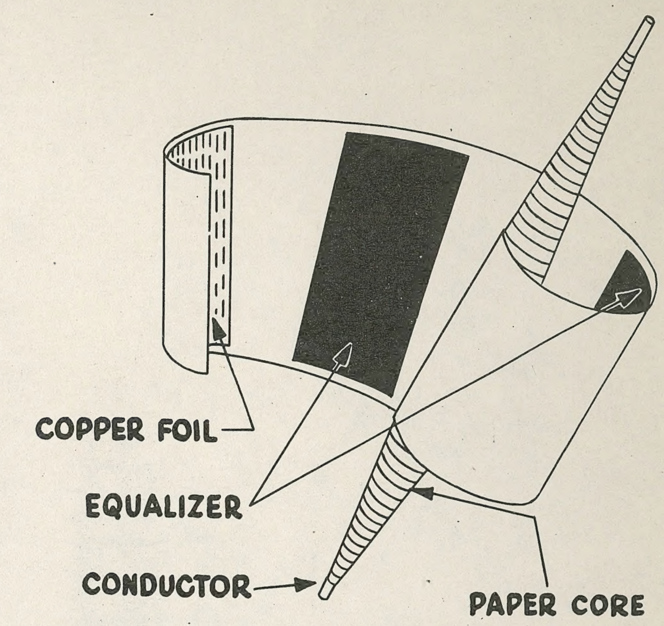


FIGURE 3. BUSHING CORE DESIGN UTILIZING FULL TURN EQUALIZERS.

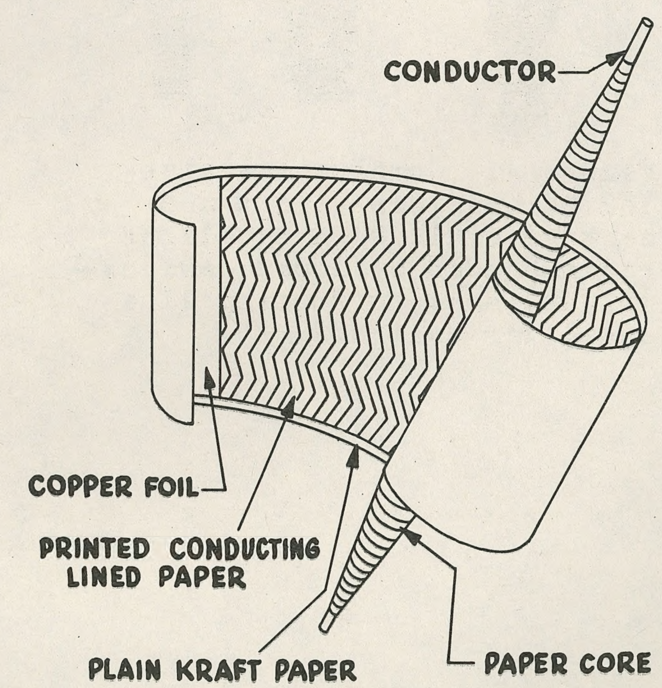
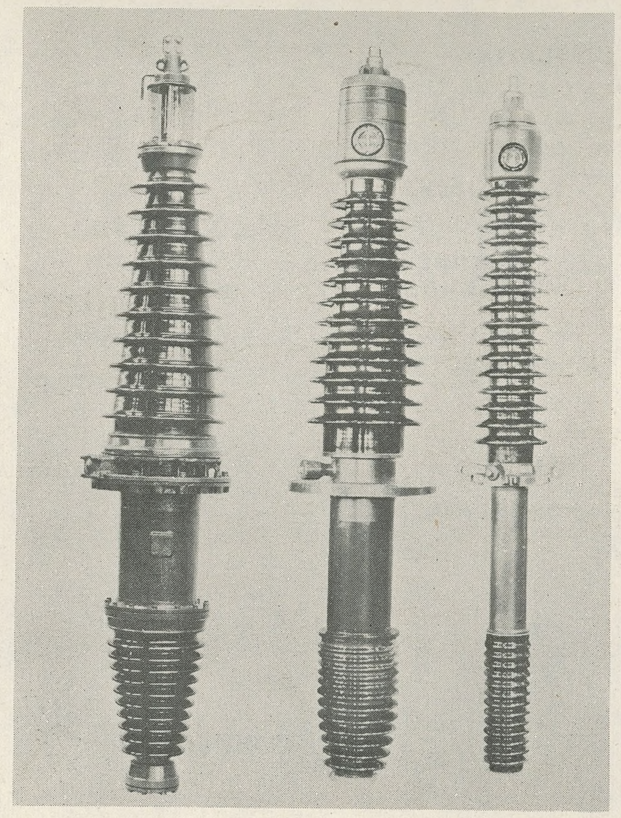


FIGURE 2. BUSHING CORE DESIGN UTILIZING NARROW CONDUCTING LINES.



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Bushings

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